AUTOMATED DIRECT OPTIMIZATION-DRIVEN ELECTROMAGNETIC DESIGN OF HIGH-FREQUENCY AND HIGH-SPEED CIRCUITS

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AUTOMATED DIRECT OPTIMIZATION-DRIVEN ELECTROMAGNETIC DESIGN OF HIGH-FREQUENCY AND HIGH-SPEED CIRCUITS

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NSERC Strategic Project Seminar Spring 1996

Milestones

Year 1	formulate mathematical approaches, acquisition of external software	Apr. 95
	create electromagnetic design benchmark problems	Oct. 95
Year 2	further development of mathematical, circuit-theory and field-theory based techniques; resolution of specialized user-oriented features	Apr. 96
	preliminary integration of software with public domain or proprietary systems to test user-oriented features; field testing; prototype available for installations at collaborating organizations	Oct. 96
Year 3	continue algorithm development and testing; workshop for Canadian participants	Apr. 97
	production testing and promotion of documented software; arrange installation at interested Canadian organizations	Oct. 97

Overview of the Presentation

benchmark EM design problems

- double folded stub filter
- attenuator
- HTS filter
- interdigital combline filter
- frequency doubler
- waveguide transformers

user-defined parameterization of arbitrary structures

parallel computing

Space Mapping

EM optimization of 3D structures

work in progress

Previous Work: Challenges of Automated EM Optimization

(*Bandler et al., 1993, 1994*)

drastically increased analysis time

discrete nature of some EM solvers

continuity of optimization variables

gradient information

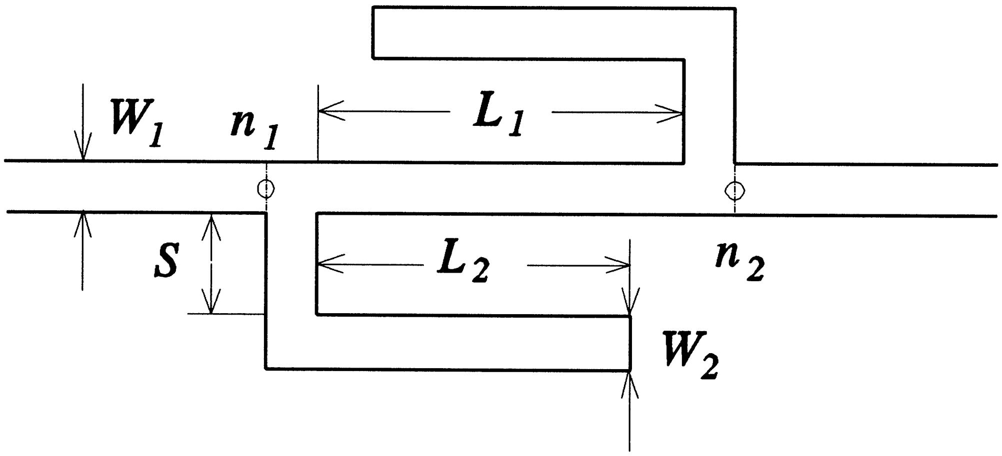
interpolation and modeling

integrated data bases

original Space Mapping algorithm

Benchmark EM Design Problems
A Double Folded Stub Filter

(*Jim Rautio, Sonnet Software*)

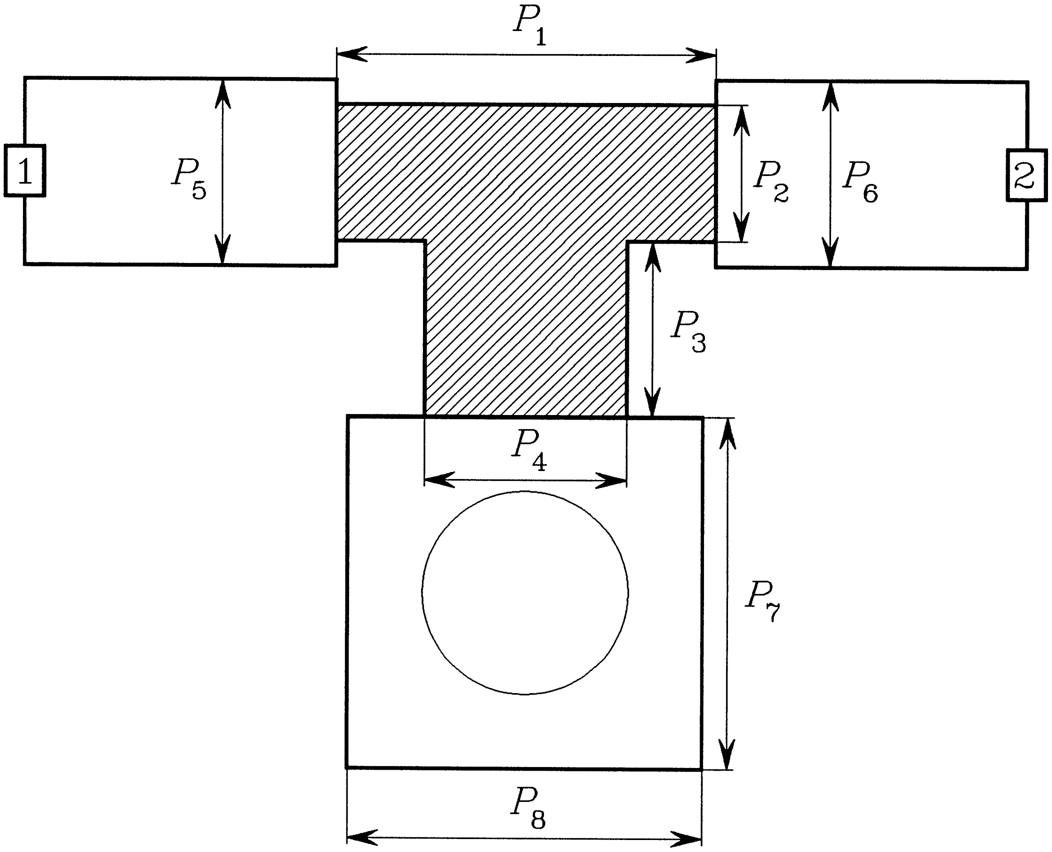


for bandstop filter applications

substantially reduced filter area w.r.t. the conventional double stub structure

substrate thickness is 5 mil and the relative dielectric constant is assumed to be 9.9

Benchmark EM Design Problems
A 10 dB Distributed Attenuator
(*Dan Swanson, Watkins-Johnson*)



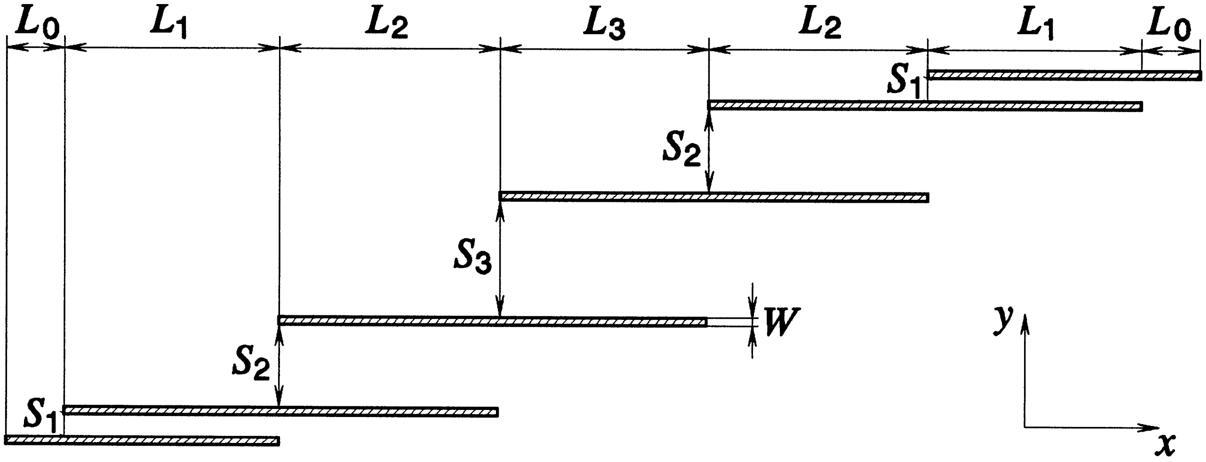
built on a 15 mil thick substrate with relative dielectric constant of 9.8

metallization of a high resistivity (50 Ω/sq)

the feed lines and the grounding pad are assumed lossless

Benchmark EM Design Problems
An HTS Filter

(*Chuck Moskowitz and Salvador Talisa, Westinghouse*)

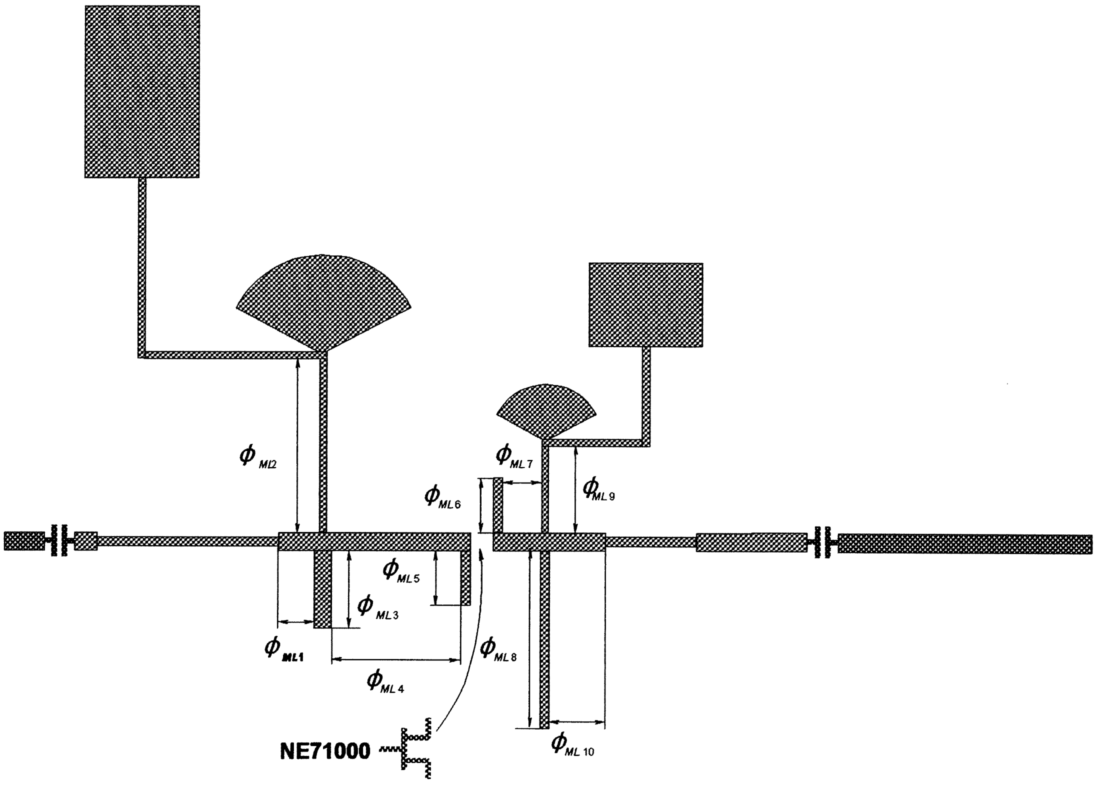


high-temperature superconducting four pole quarter-wave parallel coupled-line microstrip filter

high relative dielectric constant (more than 23) of the substrate material (lanthanum aluminate)

narrow bandwidth (1.25%)

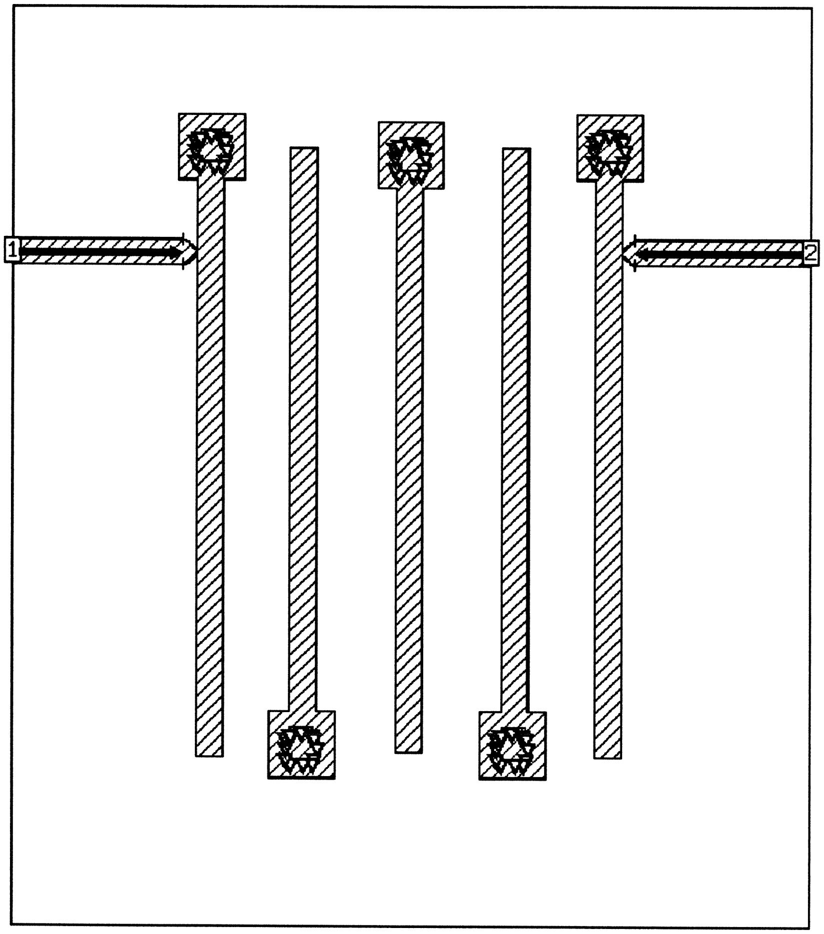
Benchmark EM Design Problems
A Nonlinear FET Class B Frequency Doubler
(Microwave Engineering Europe, 1994)



the linear subcircuit is defined as one optimizable structure with 10 variables

requires integration of large-signal harmonic balance of nonlinear circuits with active devices into EM-based optimization

Benchmark EM Design Problems
An Interdigital C-Band Filter
(Dan Swanson, Watkins-Johnson)



a five-pole interdigital filter with tapped lines

drawn using *xgeom* of Sonnet Software

User-Defined Parameterization of Arbitrary Structures

to optimize shapes and dimensions of geometrical objects by automatically adjusting the user-defined parameters subject to implicit geometrical constraints

work has included development of theory and algorithms employing concepts from analytic geometry, supported by graphical interfacing

EM simulators deal directly with the layout representation of circuits in terms of absolute coordinates

geometrical coordinates are implicitly related to designable parameters

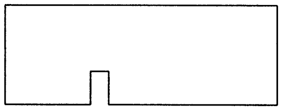
geometrical parameterization is needed for every new structure

using a graphical layout editing tool the user marks the evolution of the structure as the designable parameters change

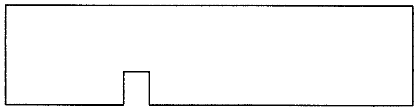
a mapping between the geometrical coordinates and the designable parameter values is established

possible extension: establish rules and rule checkers

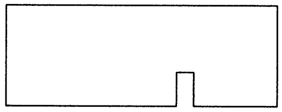
Various Object Evolutions



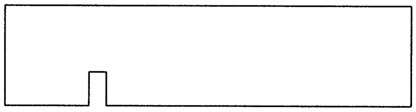
(a)



(b)



(c)



(d)

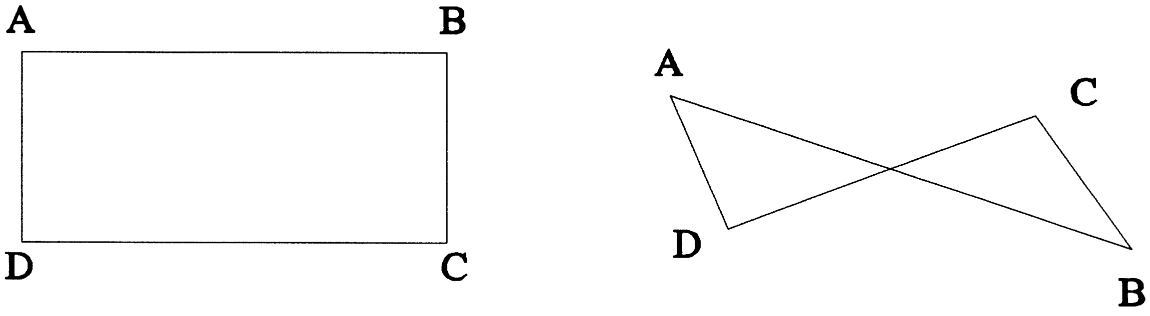
(a) initial geometry

(b) proportional expansion of the whole structure along the x axis

(c) only the location of the slit in the fixed line is allowed to change

(d) only the segment to the right of the slit is allowed to expand

Possible Pitfalls of Arbitrary Movement of Vertices

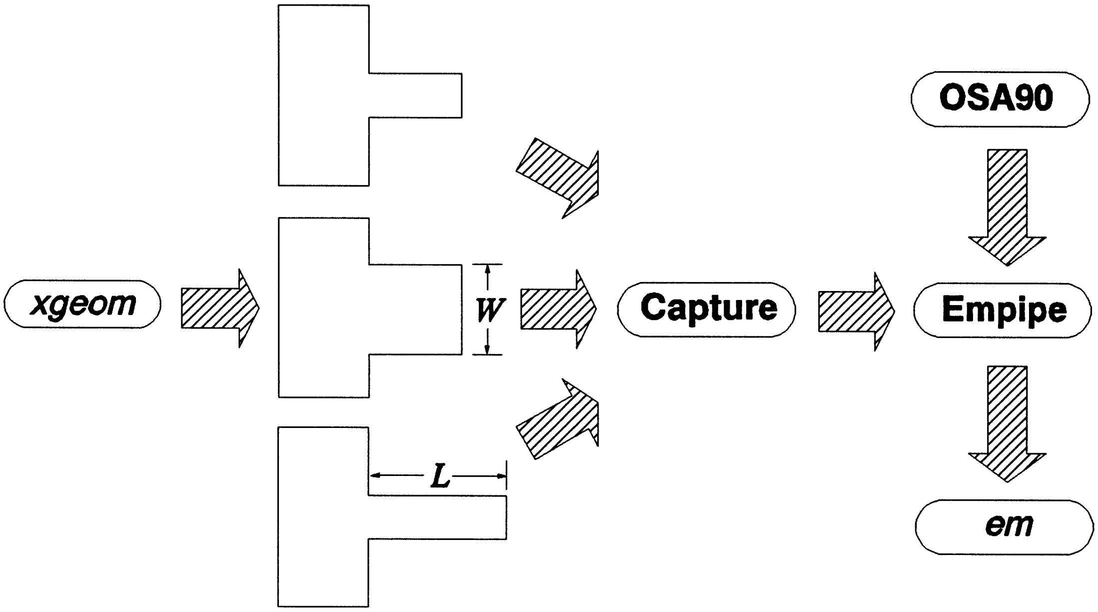


(a) (b)

(a) initial geometry

(b) an unwanted result due to an arbitrary and independent movement of vertices

Implementation of User-Defined Parameterization



Direct EM Optimization of the Frequency Doubler
(*Bandler, Biernacki, Cai, Chen and Grobelny, 1995*)

involves optimization of an arbitrary planar structure

the complete structure between the two capacitors is considered as a whole and simulated by Sonnet's *em*

Empipe links *em* simulations to the optimizer

the performance of the overall circuit is directly optimized with 10 optimization variables

design specification:

conversion gain > 3 dB
spectral purity > 20 dB

at 7 GHz and 10 dBm input power

Interface to Various CAD Simulators

to expand our interprocess pipe communication (IPPC) technique for integrating simulators into optimization systems

capable of handling any specific syntax of a given simulator

simulation results captured from the output files of those simulators and returned to the optimizer

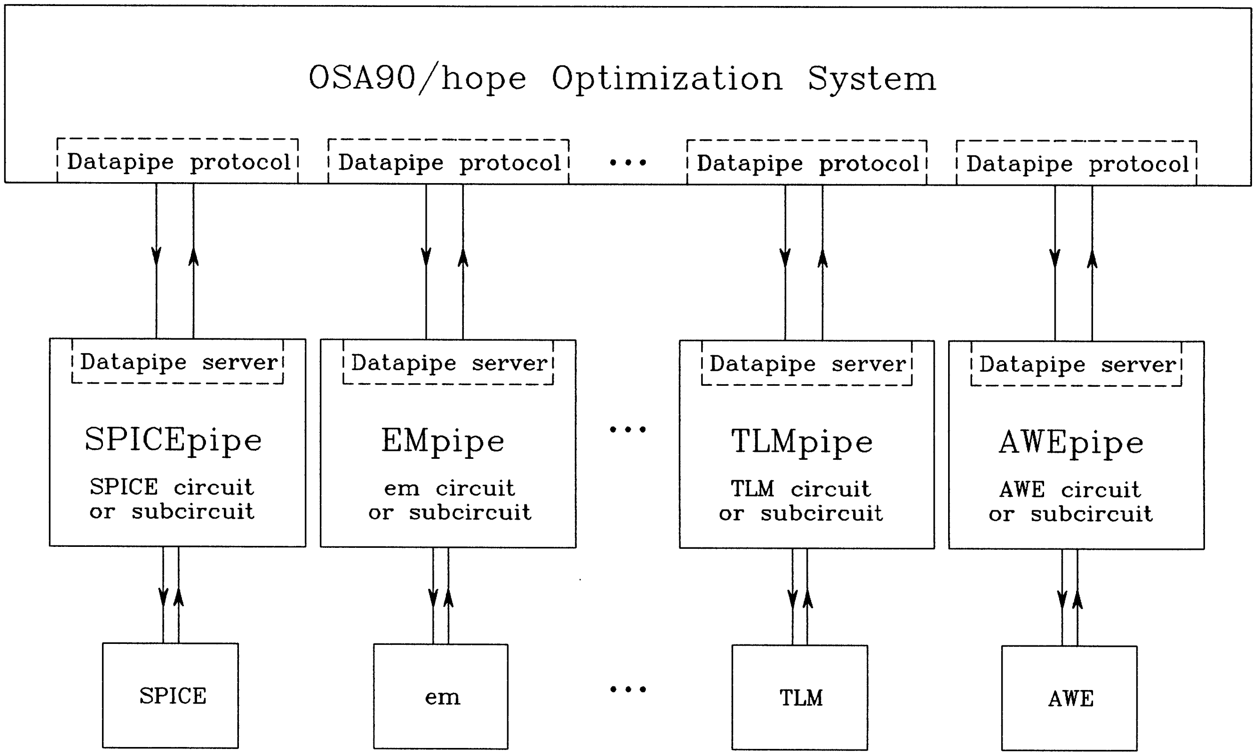
to be capable of learning the output format of any specific simulator

multi-level distributed calculations with design variables defined at different levels

interpolation/modelling capability and database management

parallel computing as an effective means of speeding up CPU intensive EM optimization

Integration of Various CAD Tools



Parallel Computing Options

multiprocessor computers and specialized compilers vs. distributing EM analyses over a computer network

the overhead of parallelization is negligible as compared to the CPU-intensive EM analyses

splitting at the component/subcircuit level

suitable when several EM simulation results are needed simultaneously

  off-grid interpolation

  numerical gradient estimation

  multiple outcomes in statistical analysis

suits best the operational flow of interpolation, optimization and statistical analysis

Organization of Parallel Computing

organized by Empipe from one of the networked computers (master host)

using standard UNIX protocols (remote shell and equivalent hosts) an EM analysis is started on each of the available hosts

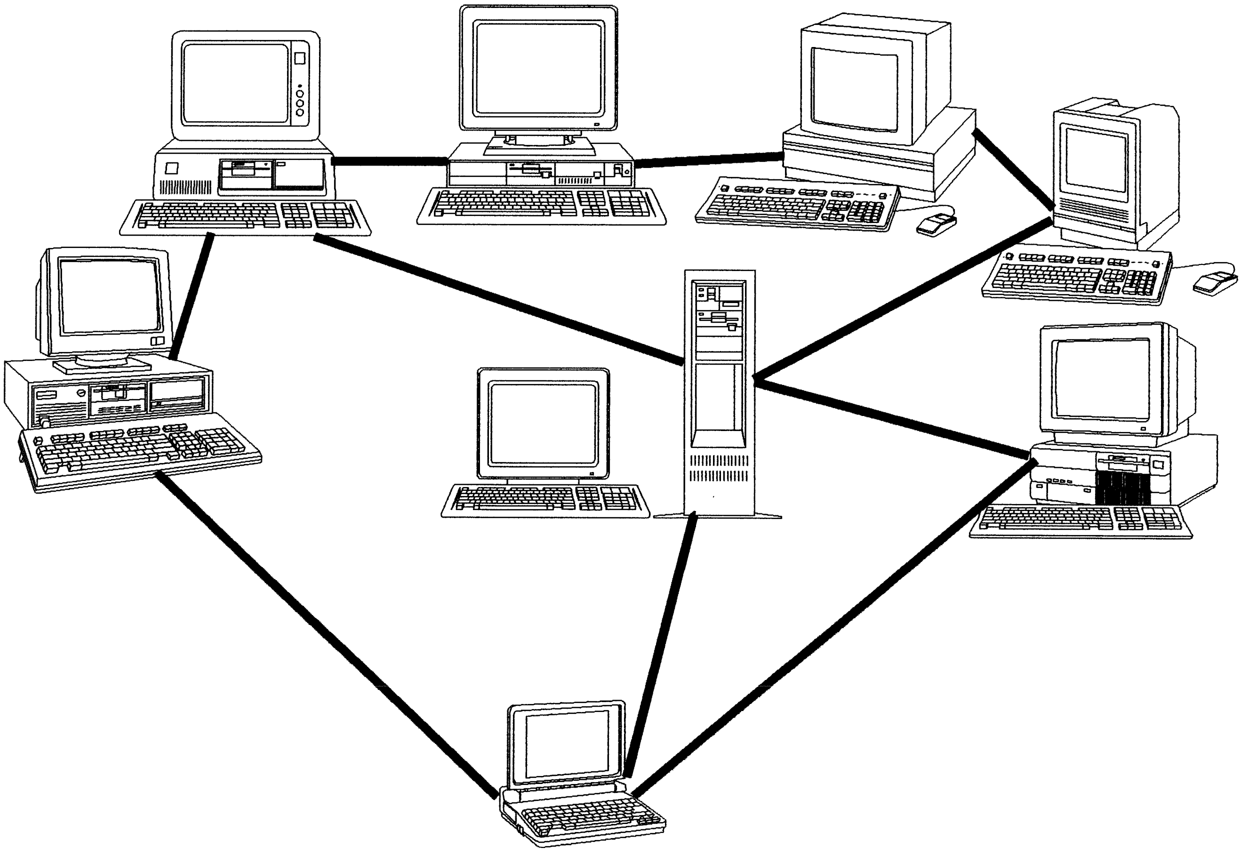
when the analysis is finished on a host, the next job, if any, is dispatched to that host

EM simulation results are gathered from all the hosts and stored in a data base created on the master host

no platform specific mechanisms

applicable to both local and wide area networks of heterogeneous workstations

Heterogeneous Network of Computers



Statistical Design of the Attenuator

design specifications (from 2 GHz to 18 GHz)

$9.5 \text{ dB} \leq$ insertion loss $\leq 10.5 \text{ dB}$

return loss ≥ 10 dB

the structure, treated as a whole, is described by 8 geometrical parameters

designable: 4 parameters describing the resistive area

statistical variables: all 8 parameters (with a standard deviation of 0.25 mil)

em simulation at a single frequency requires about 7 CPU minutes on a Sun SPARCstation 1+

Parallel Computing in Nominal Design of the Attenuator

30 *em* analyses

an average of 3.8 analyses run in parallel

about 168 minutes on the network of Sun SPARCstations 1+

time is reduced by 75%

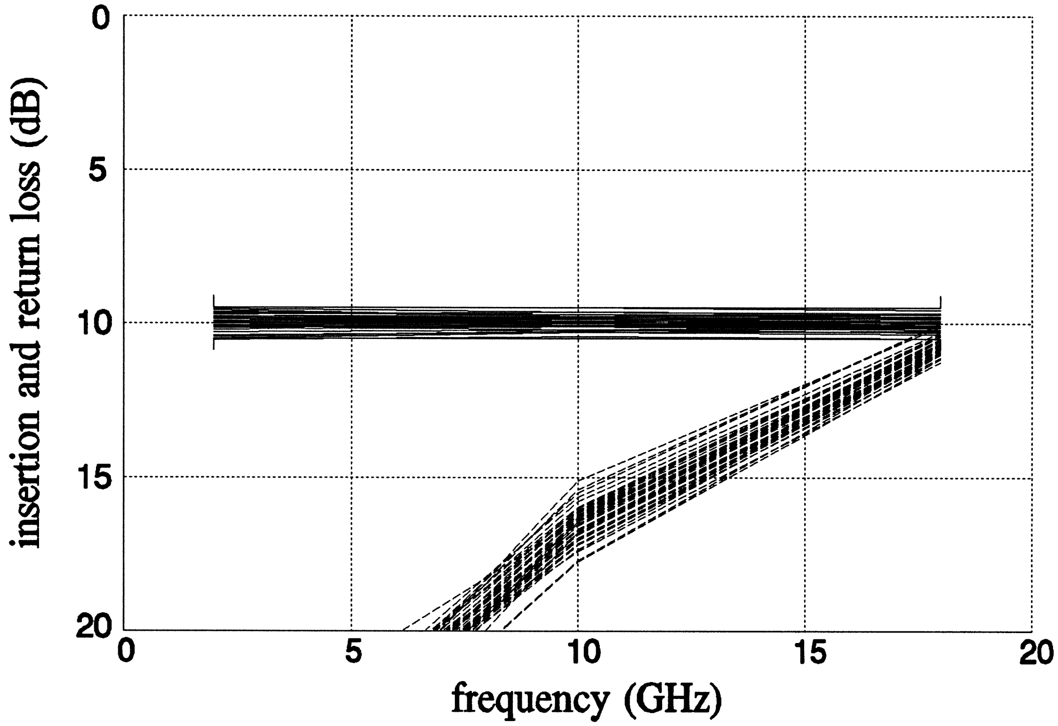
Parallel Computing in Statistical Design of the Attenuator

additional 113 *em* analyses

an average of 2.5 analyses run in parallel

time is reduced by 60%

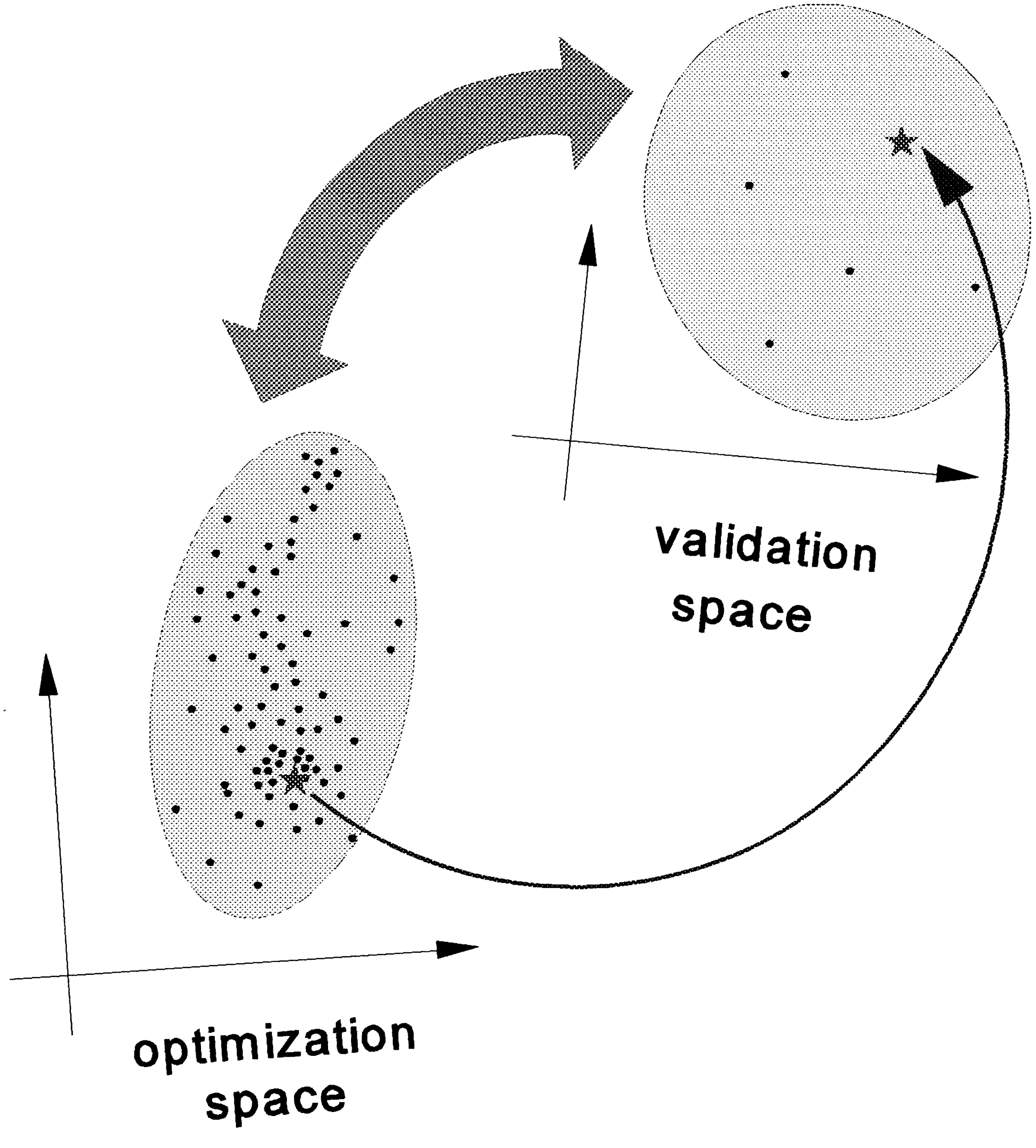
Monte Carlo Sweeps of the Attenuator Responses



yield (estimated from 250 Monte Carlo outcomes) is increased from 82% to 97%

Space Mapping

(Bandler et al., 1994)



Work on Space Mapping

develop theory and corresponding algorithms for parameter space mapping

to allow CPU intensive models to be automatically replaced during optimization by slower but also less accurate models

consider hierarchical family of models: equivalent circuit, empirical, or even decomposed or coarse grid numerical EM models, particularly for arbitrary geometries

aggressive strategy for Space Mapping

automation issues for Space Mapping

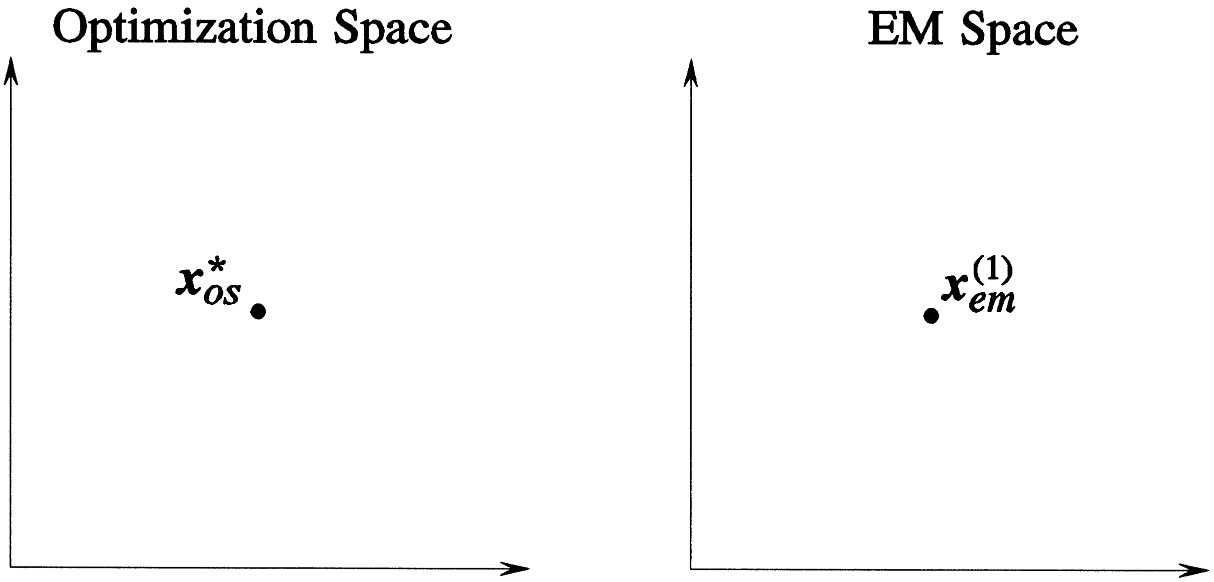
expected cornerstone for successful EM optimization

Illustration of Aggressive Space Mapping Optimization

Step 0

find the optimal design x_{os}^* in Optimization Space

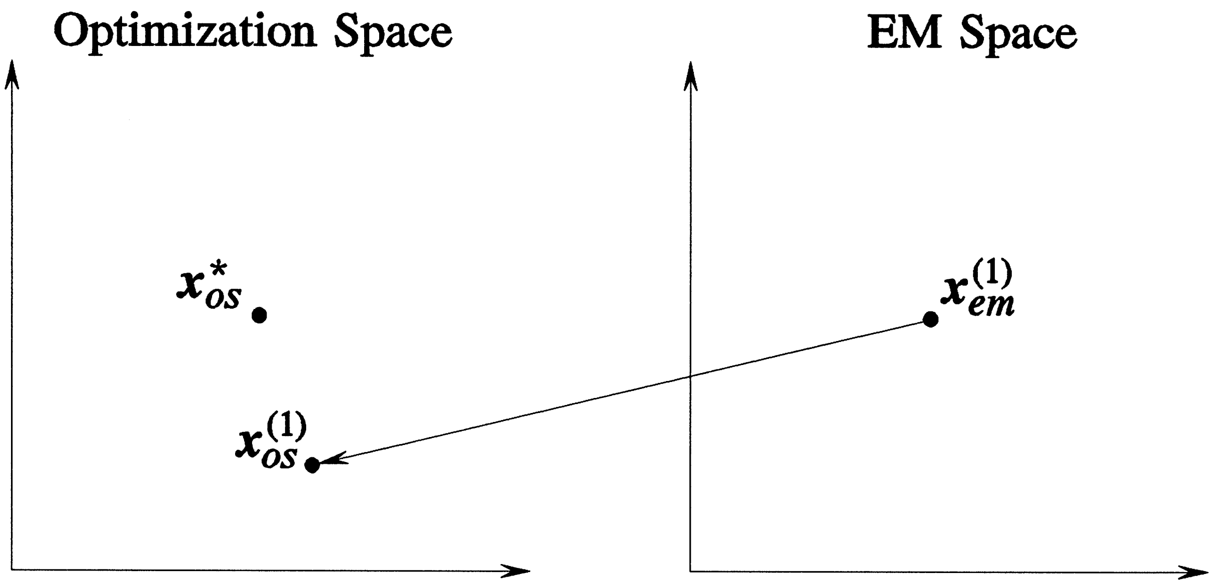
Step 1



set $x_{em}^{(1)} = x_{os}^*$ assuming x_{em} and x_{os} represent the same physical parameters

Illustration of Aggressive Space Mapping Optimization

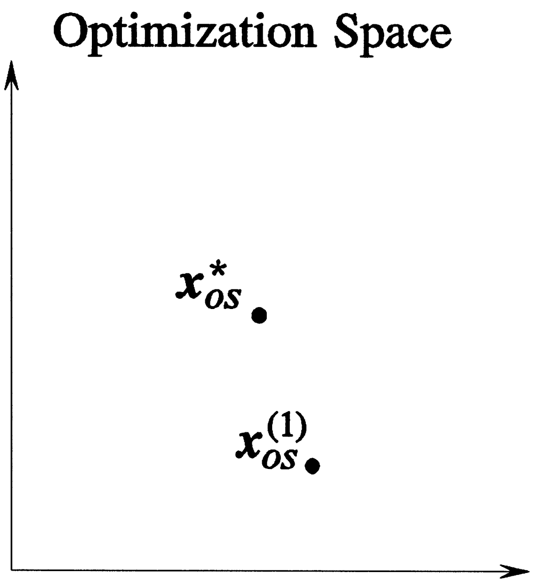
Step 2

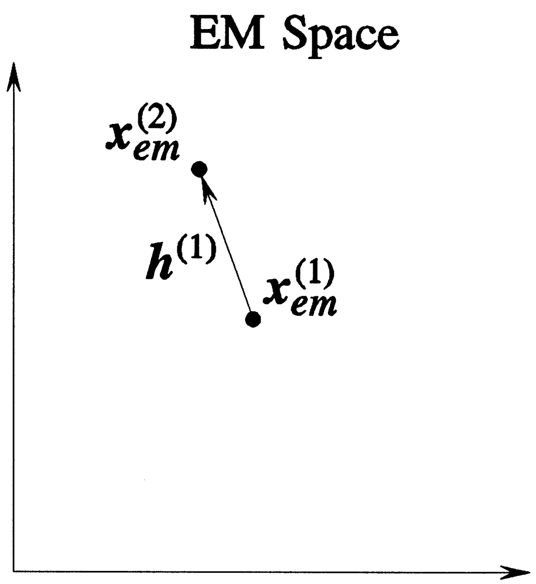


perform X_{os}-space model parameter extraction

Illustration of Aggressive Space Mapping Optimization

Step 3





initialize Jacobian approximation $B^{(1)} = \mathbf{1}$

obtain $x_{em}^{(2)}$ by solving

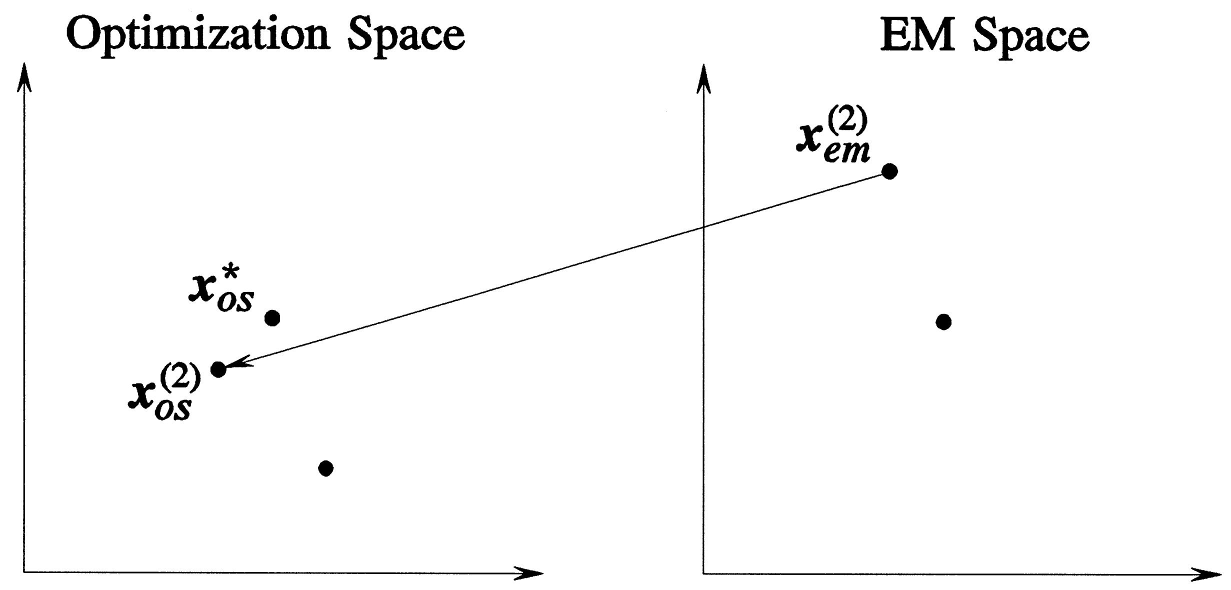
$$B^{(1)} h^{(1)} = -f^{(1)}$$

where

$$f^{(1)} = x_{os}^{(1)} - x_{os}^*$$

Illustration of Aggressive Space Mapping Optimization

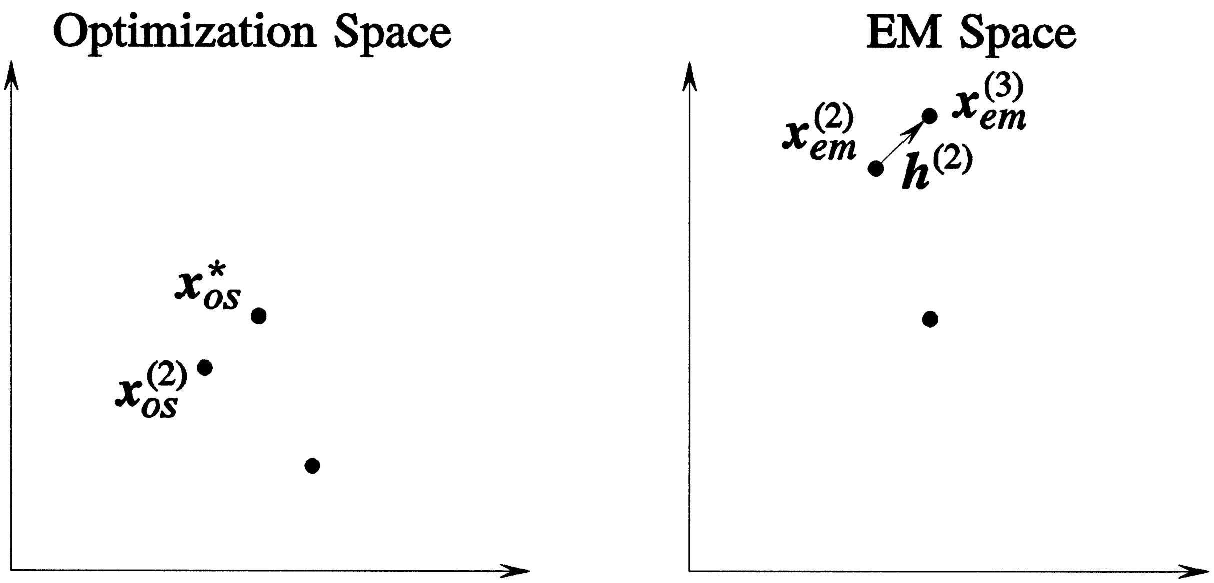
Step 4



perform X_{os}-space model parameter extraction

Illustration of Aggressive Space Mapping Optimization

Step 5



update Jacobian approximation from $B^{(1)}$ to $B^{(2)}$

obtain $x_{em}^{(3)}$ by solving

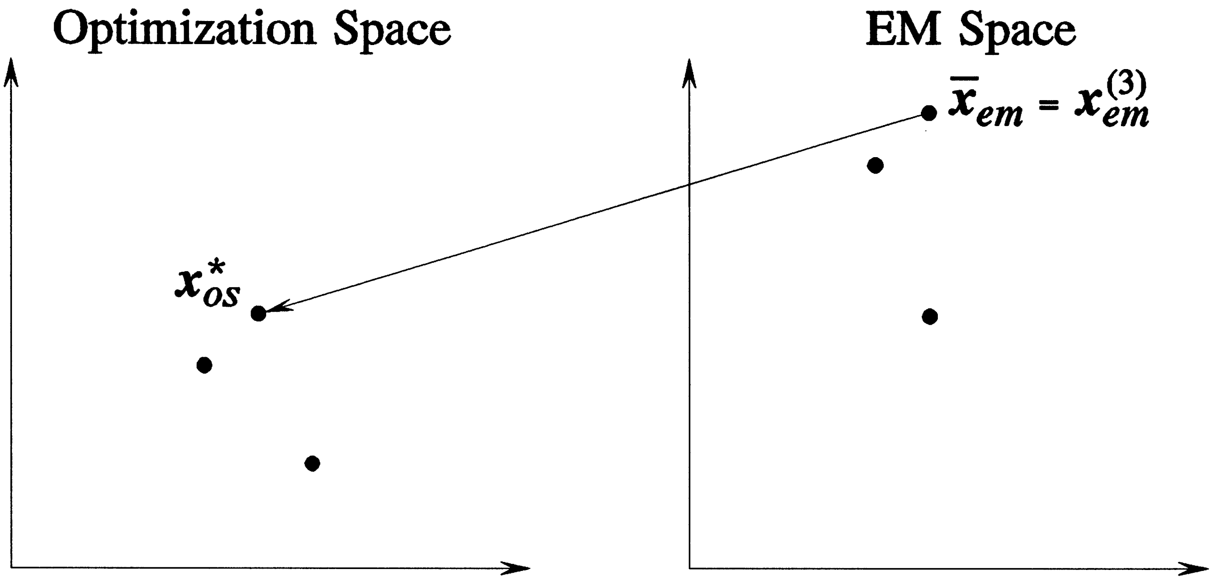
$$B^{(2)} h^{(2)} = -f^{(2)}$$

where

$$f^{(2)} = x_{os}^{(2)} - x_{os}^{*}$$

Illustration of Aggressive Space Mapping Optimization

Step 6



perform X_{os}-space model parameter extraction

if $\| x_{os}^{(3)} - x_{os}^* \| \leq \epsilon$ then $\bar{x}_{em} = x_{em}^{(3)}$ is considered as the SM solution

Automated Aggressive Space Mapping

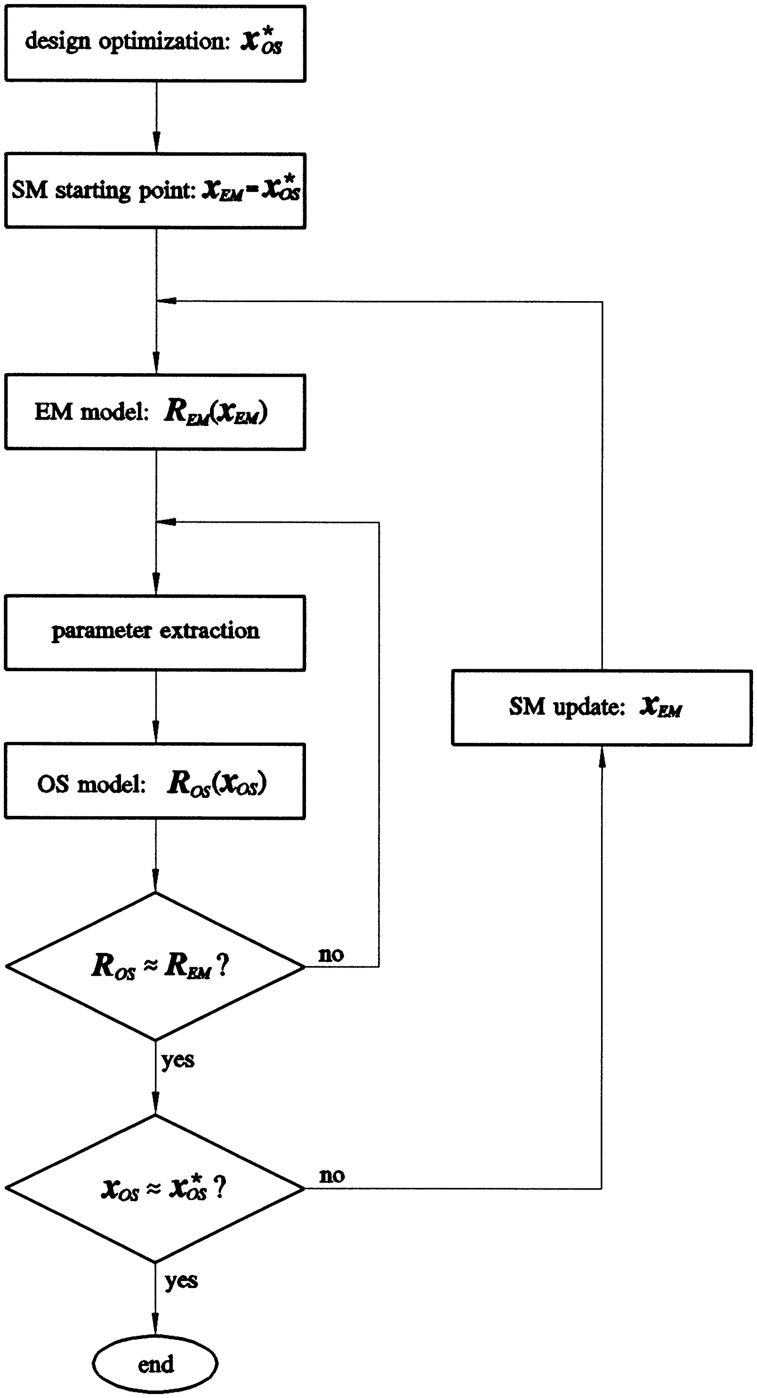
automating the aggressive SM strategy using a two-level optimization architecture

> outer level automates a generic aggressive SM loop including a Broyden update
>
> inner level implements parameter extraction for specific models

parameter extraction is crucial to SM optimization

the impact of uniqueness on the convergence of the aggressive SM strategy

Implementation of Aggressive Space Mapping



Simulation Optimization Systems Research Laboratory
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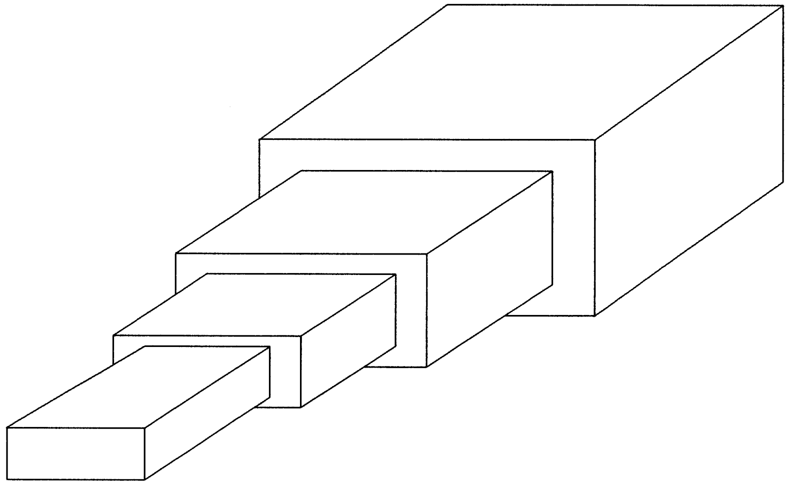
Benchmark EM Design Problems
EM Optimization of 3D Structures



a two-section waveguide transformer

two cases of Space Mapping used to align

(a) an ideal empirical model and a non-ideal empirical model

(b) an empirical model and HFSS simulations

Work in Progress

geometrical decomposition of large systems

as dictated by proximity, EM coupling or higher-order modes and interfaces to various simulators

frequency domain adjoint sensitivities for EM solvers

generalize the adjoint sensitivity analysis technique to general multi-level hierarchical systems

extend our feasible adjoint sensitivity technique (FAST) to handle space-mapped EM sensitivities

investigate how design sensitivity information is transformed/preserved through Space Mapping

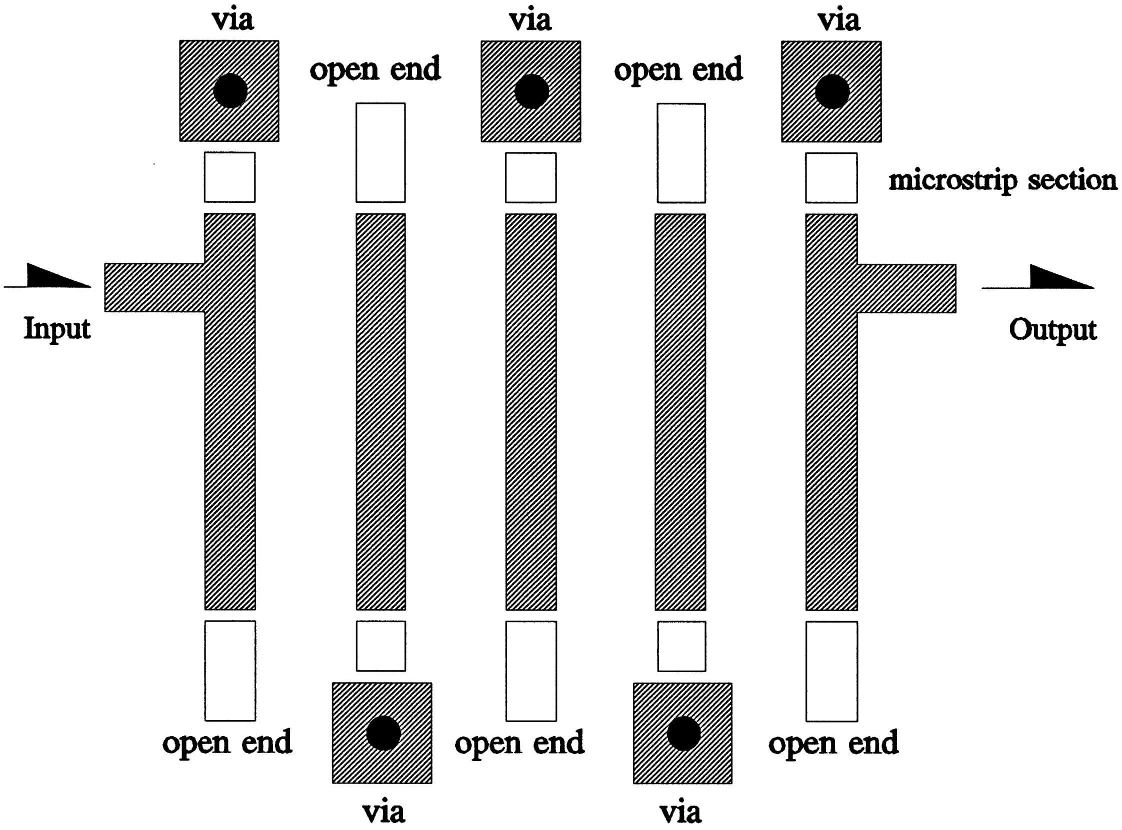
yield optimization/design centering

the ultimate benchmark for all algorithms developed within this project

many statistical outcome circuits need to be simulated and checked against design specifications

design visualization and automated documentation

A Coarse Model Using Decomposition



the shadowed areas are calculated by *em* using coarse grid

the other parts are simulated using empirical formulas

Key Interactions

Fritz Arndt
Qian Cai
Shaohua Chen
Marco Dionigi
Craig French
Bill Getsinger
Peter Grobelny
Ron Hemmers
Ya-Fei Huang
Wolfgang Hoefer
Nancy Lin
Kaj Madsen
Michel Nahkla
Dzevat Omeragic
Jim Rautio
Poman So
Roberto Sorrentino
Dan Swanson
Salvador Talisa
Quinghui Wang
Qi-Jun Zhang

Conclusions

cost-effective yield-driven design technology is indispensable

EM optimization of arbitrary geometries exerts a massive demand on resources, particularly for yield-driven design

integrated EM simulation and optimization capable of handling arbitrary structures is the future

Space Mapping promises the accuracy of EM simulation and the speed of circuit-level optimization

heterogeneous parallel CAD over a local or wide area network significantly increases design power

user-defined parameterization allows analysis and optimization of complicated structures as a whole

integration of simulators from various sources into automated design optimization with interpolation, response function modeling and data base techniques will immensely reduce the overall design time

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